SYNOPTIC ANALYSES OF THE 5-, 2-, AND 0.4-MILLIBAR SURFACES FOR THE IQSY PERIOD

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ABSTRACT

Rocket data from the Meteorological Rocket Network and other sources, in addition to high-level rawinsonde observations, are being employed to analyze a series of 5-, 2-, and 0.4-mb. charts. The broadscale analyses are being constructed for each week of the International Years of the Quiet Sun period, and primarily cover the North American and adjacent ocean areas. Methods employed for processing the various types of data as well as the analysis procedure are described.

Analyses completed thus far confirm the existence of large-scale systems, such as the wintertime polar cyclone and the Aleutian anticyclone, to at least the level of the stratopause. In addition there is evidence of large-scale periodic oscillations in the heights of upper-stratospheric constant-pressure surfaces during autumn and early winter. Furthermore, a significant tidal component is apparent in summertime rocketsonde winds, for which adjustment must be made in order to obtain consistent quasi-synoptic patterns.

1. INTRODUCTION

The Upper Air Branch of the National Meteorological Center (NMC), Weather Bureau, with the aid of a grant from the U.S. Army Materiel Command, has undertaken the task of analyzing a series of constant-pressure charts based on rocketsonde and very-high-level rawinsonde data. The area of analysis is primarily North America and adjacent ocean areas and the period is the International Years of the Quiet Sun (IQSY), January 1964 through December 1965. Previous studies [10, 18, 21] demonstrated the feasibility of utilizing data from the Meteorological Rocket Network (MRN) [12, 23] for the representation of circulation patterns in the upper stratosphere and lower mesosphere (the region from approximately 30 to 60 km.). However, the available data permitted the analysis of only occasional samples, which provided at best a limited climatological view of the region.

In recent years the frequency of rocketsonde observations has increased significantly. Although data coverage for the 30- to 60-km. layer is still extremely sparse in comparison with that obtained at lower levels with the present-day rawinsonde network, it nevertheless appears to be adequate for preparation of broadscale synoptic analyses on at least a weekly basis.

One of the analysis methods previously developed [18] for the portrayal of synoptic conditions in the upper stratosphere required a 10-mb. chart constructed from rawinsonde data to be used as a base or foundation for application of hydrostatic build-up techniques. However, summaries of heights attained by rawinsondes during the IQSY and the results of high-level analysis experiments have indicated that those observations frequently penetrate to at least the 5-mb. level. Therefore a pilot series of analyses was undertaken in order to determine the feasibility of raising the base level to 5 mb. It was found that consistent results could be obtained, provided daily 10-mb. charts [6] were utilized as an aid in the construction of these analyses.

While the 5-mb. chart is based principally on rawinsonde reports, rocket observations constitute the primary data source for the higher-level analyses. Since the rocket winds and temperatures are obtained and reported as functions of geometric height, whereas pressure is computed, constant-level (e.g., 40 and 50 km.) charts would seem to be the logical form in which to portray synoptic patterns. However, this representation would require that the 5-mb. chart be transformed to a constant-height map, so that differential analysis methods could be applied for the construction of charts at successively higher levels. The transformation is difficult in that it demands a knowledge of the mean temperature field in the layer between the 5-mb. surface and the corresponding standard [4] constant-height surface (approximately 36 km. in this case). At northern latitudes in winter, when the 5-mb. surface is well below 36 km., a mean temperature field cannot be readily obtained. A further and well known disadvantage of constant-level analysis is the dependence of the geostrophic wind equation on density, which results in the need for a separate wind scale at each level.

Constant-pressure analysis of rocketsonde data, on the other hand, is not without its shortcomings. Since pressure is not a measured parameter in such observations, an initial estimate of the height of the pressure surface must be made before temperature and wind values can be extracted. An alternate method of obtaining this height is to compute the pressure-height profile from the reported temperatures, utilizing rawinsonde data to initiate the integration of the barometric equation [19].

After consideration of the aforementioned factors, it was decided that constant-pressure analysis was the optimum method, both technically and economically. The IQSY series of analyses at weekly intervals thus includes 5-, 2-, and 0.4-mb. (approximately 36-, 42-, and 55-km., respectively) charts nominally portraying synoptic conditions on each Wednesday of the analysis period. In addition to description of the techniques and theory employed in obtaining these analyzed charts, a brief discussion of large-scale features apparent from preliminary analyses is also included in the following sections.

2. PROCESSING OF RAWINSONDE DATA

The preparation of high-level data for analysis presents a myriad of problems. Some of the difficulties encountered in the use of rawinsonde information, such as the achievement of compatibility between daytime and nighttime observations, extrapolation and interpolation of data, and identification of erroneous reports, have been summarized by Finger et al. [9]. In lieu of the application of sophisticated computer methods to 5-mb. data, the last of these problems, and to some extent the second as well, must be solved by the analyst. However, compensation for the systematic errors in reported temperatures and heights, presumably introduced by effects of radiation on the radiosonde thermistor, can be, and has been in previous work, accomplished in pre-analysis computer processing of observational data.

The temperature and height adjustments designed to compensate for instrumental radiation errors are applied to all 5-mb. rawinsonde reports. Initially an adjustment is made, which in essence reduces daytime values to the level of those reported from nighttime observations. The magnitudes of these day-night adjustments, which are intended to account for the effects of solar heating on the rod thermistor, were determined with the aid of a computer program which calculates monthly mean differences between reported daylight and darkness values. Input to this program consisted of all available 5-mb. data for 1964 from stations in North America and adjacent areas that employ United States outrigger-type radiosonde instruments.

Monthly mean day-night temperature and height differences for a group of North American stations are shown in figure 1 as functions of solar elevation angle at the time the daylight radiosonde penetrated the 5-mb. level. Similar computations had previously been carried out [7] for all levels from 100 to 10 mb. A comparison revealed that the 5-mb. differences are approximately

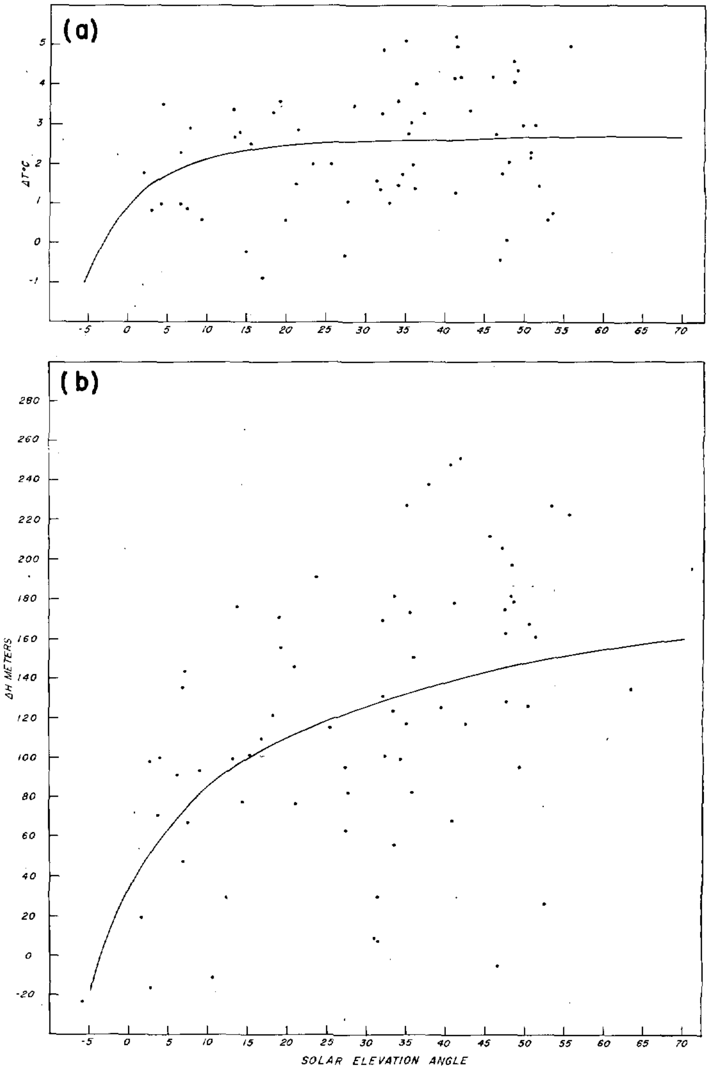

FIGURE 1.—Monthly mean day-night (a) temperature differences and (b) height differences at the 5-mb. level as a function of solar elevation. Data points represent $(1/N)\Sigma(T_d-T_n)$ and $(1/N)\Sigma(H_d-H_n)$, respectively.

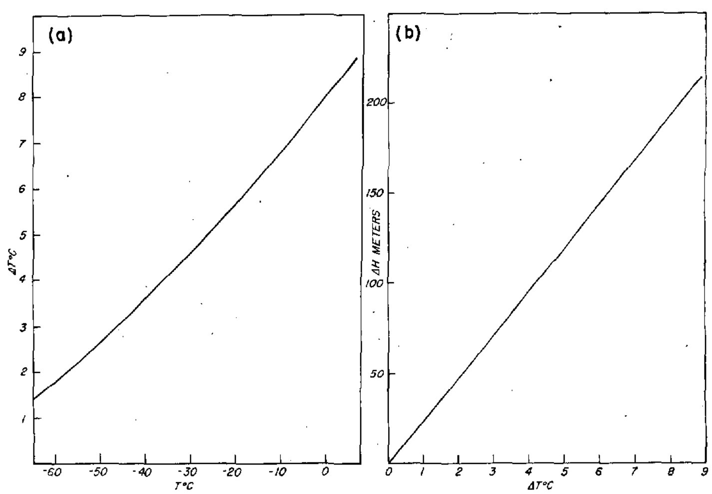

FIGURE 2.—Corrections for long-wave radiational error of radiosonde thermistor at 5 mb.

72265 WEEK OF WEDNESDAY 1964 10 28 72265

				WIND VELOCITIES				TEMP. GRADIENTS AND THERMAL WINDS							HEIGHTS AND TEMPERATURES			
YR	MO	DA	HR	5-MB DDD FFF	7-MB DDD FFF	4-MB DDD FFF	3-MB DDD FFF	7- 5 MB GRADT	DDD FFF	7- 4 MB GRADT	DDD FFF	5- 4 MB GRADT	DDD FFF	5-MB SUN ANGLE	5-MB HHHHHTTT	7-MB HHHHHTTT	4-MB HHHHHTTT	3-MB HHHHHTTT
64	10	26	12		276									5.1 *	5610-38 *	3326-45		
					56									COR *	5640-36 *			
64	10	27	0		266									-18.9		3433-43		
					47													
64	10	27	12		276									4.9		3361-47		
					76													
64	10	28	0	* 273 *	264			1.15	305					-19.0 •	5598-46 *	3370-48		
				* 82 *	66				19					COR •	5674-43 •			
64	10	28	12		275									4.8 *	5525-40 *	3259-46		
					54									COR *	5551-38 •			
64	10	29	12		277									4.6		3383-44		
					58													
64	10	31	0		276									-19.5		3248-47		
					62													
64	10	31	12	* 263 •	266	280		0.37	242	0.95	303	2.16	316	4.2 •	5479-40 •	3203-45	7012-37	
				• 49 •	43	66			6		27		24	COR *	5509-38 •			

FIGURE 3.—Computer output listing of high-level rawinsonde data from Midland, Tex. (72265), for the week centered on Wednesday October 28, 1964. Winds (DDD, FFF): degrees and knots. Temperature gradients (GRADT): °C. per deg. latitude. Solar elevation angles (SUN ANGLE): degrees and tenths; negative angles are for nighttime reports. All temperatures (TTT): °C.; heights (HHHHH): geopot. m., with the 10's of km. digit (3) omitted. Both reported and, for the 5-mb. level, corrected (COR) values are shown.

equal to those at 10 mb., although the dispersion of plotted values increases substantially at the lower pressure.

Theoretical and laboratory studies [1, 14] of the rod thermsitor used in present-day radiosondes indicate that a significant error may be induced by infrared cooling at stratospheric levels above 10 mb. Therefore a second adjustment (fig. 2) based on estimates developed by Barr [3], is added to all 5-mb. "nighttime" data, including observations actually in darkness as well as daytime reports that have been adjusted for solar-radiation error. The magnitude of the temperature correction is a function of reported temperature, while the height adjustment varies linearly with the temperature correction.

Rawinsonde data utilized for the 5-mb. analyses are processed by computer methods. Input to the program consists of North American and adjacent-area observations for the 7-, 5-, 4-, and 3-mb. levels in the form of punched cards obtained from the National Weather Records Center. Output listings, an example of which is shown in figure 3, include all observations for one week at each station. The data for levels other than 5 mb. are also listed in order to supply the analyst with as much supplementary information as possible. Thermal winds and corresponding horizontal temperature gradients are computed for the layers from 7 to 5, 7 to 4, and 5 to 4 mb. In addition, the 5-mb. temperature and height adjustment schemes, including calculation of the required solar elevation angles, have been incorporated into the system.

3. PROCESSING OF ROCKETSONDE DATA

Rocket winds and temperatures form the basis for analysis of the 2- and 0.4-mb. charts and in addition are

(a) METEOROLOGICAL ROCKET SOUNDING DATA

RP | RP NAME + PLACE | DATE Y M D | TIME Z | TR | RT | WS | TS | RP | IJ | QD | WHT | WHB | THT | THB

26406 FORT GREELY, ALASKA 64 10 28 2007 -03 01 02 01 COR

	ROCKET WINDS			THERMODYNAMICS					COMPOSITION				RAOB					
TH	A MSL	COMP	WNDS	A MSL	TDC	PMB	D	SOS	A MSL	O	ED	LAR	PMB	A MSL	COMP	WNDS	RH	TDC
040	6234	-022	-020	6496	-27.5	000.12	00.167	314					0007.1	3353	-011	+007		-47.3
045	5830	-040	+016	5438	-00.5	000.46	00.591	331					0008.9	3200	-008	+008		-46.7
050	5480	-052	+014	4780	-10.5	001.06	01.403	325					0011.2	3048	-007	+012		-46.2
060	5076	-040	+019	4363	-07.0	001.80	02.356	327					0014.0	2896	-004	+011		-47.8
070	4658	-026	+019	4120	-12.5	002.46	03.283	324					0017.3	2743	+000	+007		-49.1
080	4338	-020	+020	3936	-23.0	003.13	04.362	317					0021.9	2591	-001	+008		-49.1
090	4081	-014	+014	3716	-29.5	004.23	06.051	313					0027.7	2438	-001	+013		-49.6
100	3875	-017	+013	3630	-26.5	004.77	06.729	315					0043.9	2134	+007	+008		-51.8
110	3710	-011	+011	3570	-31.0	005.18	07.447	312					0069.2	1829	+002	+011		-45.7
120	3555	-006	+011	3350	-41.5	007.09	10.655	305					0108.5	1524	+007	+007		-44.2
130	3421	-003	+009	3300	-44.5	007.63	11.617	303					0171.6	1219	+007	+006		-46.3
140	3302	-008	+005	3196	-45.5	008.90	13.613	302					0272.1	0914	+009	+001		-52.7
150	3196	-005	+006	3140	-40.5	009.66	14.463	306					0434.0	0610	+008	+000		-41.7
160	3090	-002	+005	3104	-43.0	010.18	15.411	304					0664.4	0305	+011	+000	70	-18.6
170	2998	-001	+018	2998	-42.5	011.90	17.968	304					0941.7	0040	+001	+001	93	-05.8
180	2913	+005	+012	2930	-45.5	013.15	20.128	302					0010.0	3102	-009	+010		-45.6
190	2832	-003	+011	2880	-44.0	014.17	21.534	303					0050.0	2036	+008	+006		-49.8
200	2756	+001	+011	2790	-44.5	016.18	24.655	303					0100.0	1577	+008	+007		-45.2
220	2667	+003	+011	2730	-47.0	017.70	27.258	301					0500.0	0511	+012	-004	45	-34.0
240	2546	+004	+010	2354	-47.0	031.09	47.686	301					0700.0	0266	+011	+001	90	-15.8
260	2440	+004	+010	2274	-43.5	035.02	53.119	304										
280	2350	+005	+009	2180	-45.5	040.26	61.606	302										
300	2269	+005	+007															
320	2195	+005	+010															
340	2126	+005	+011															
360	2059	+006	+005															
380	1994	+005	+005															
400	1936	+010	+006															
420	1880	+014	-002															
440	1820	+005	+006															
460	1767	+010	+011															

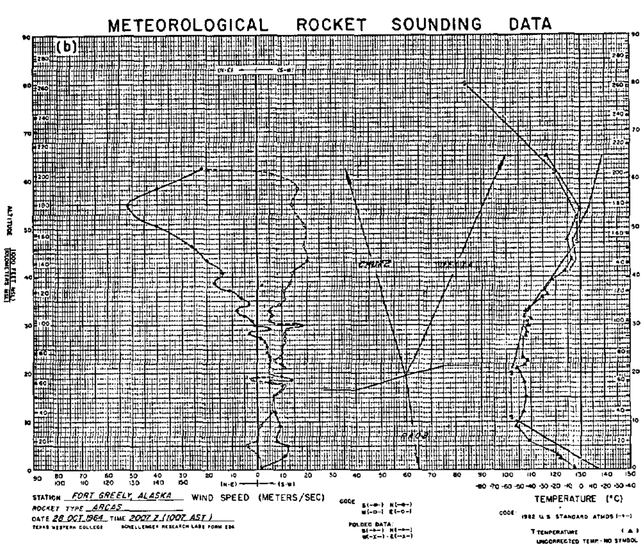

FIGURE 4.—Rocketsonde data as presented in the *Data Report, Meteorological Rocket Network Firings* [11]: (a) listings, (b) graphical representation.

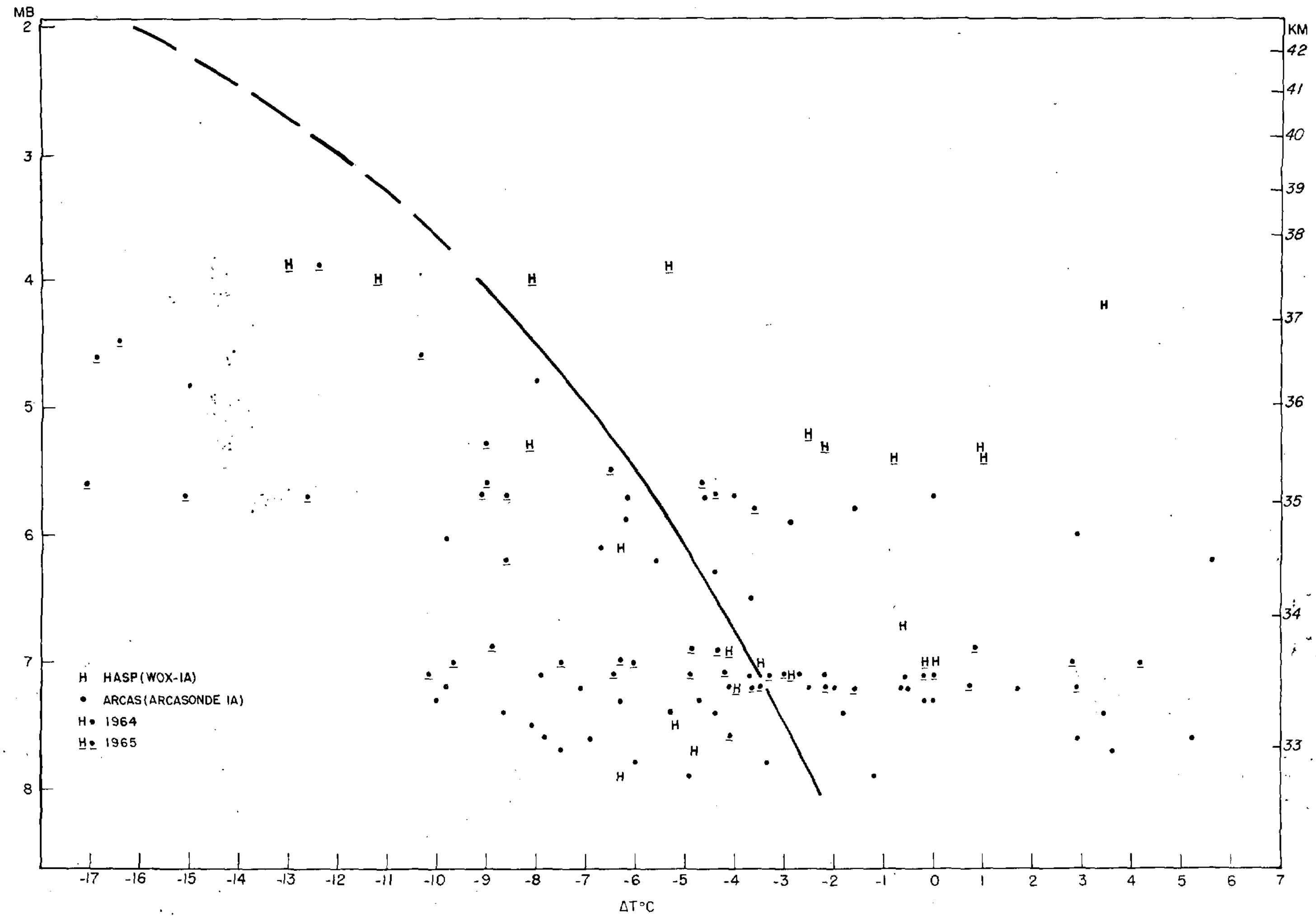

FIGURE 5.—Differences between rocketsonde and rawinsonde temperatures measured at nearly the same time and level (rawinsonde minus rocketsonde). Curve represents least-squares fit of ΔT versus log P (after Finger and Woolf [8]).

used to supplement rawinsonde observations at 5 mb. The information for each week is extracted from the *Data Report, Meteorological Rocket Network Firings* [11]. An example of the format employed for the Data Reports is shown in figure 4. The listings (fig. 4a) include component winds, observed temperatures, and computed pressures at selected heights. Although the rocket data are available in a form suitable for computer application, the desired temperatures and winds are at present selected from the graphs (fig. 4b).

The basic steps in the extraction of rocketsonde information and the computation of heights for the 5-, 2-, and 0.4-mb. surfaces are as follows:

1. Temperatures observed above 40 km. with the Arcasonde 1A instrument are reduced in accordance with a recent theoretical study [5]. The magnitude of this correction increases to about 4° C. at 50 km. and 12° C. at 60 km. Published data obtained by the Deltasonde generally include a correction [20] and hence are utilized without further adjustment. No correction schemes are available for other instruments. However, the great majority of observations have been made with the Arcasonde and Deltasonde.

2. As mentioned previously, an initial estimate of the height field must be made before the temperature at a given constant-pressure surface can be selected. This estimate is obtained by extrapolating the trend of the height field from the analyzed charts for the previous two weeks. The selected temperature value is then utilized with that derived from the previously completed lower-level analysis for the computation of a layer-mean temperature.

3. Heights for the upper surface are computed hydrostatically with the aid of the mean temperature obtained as described above.

4. Since the analyses are intended to portray synoptic-scale features, portions of wind component profiles that exhibit rapid oscillations in the vertical are smoothed. An objective smoothing procedure is being programed for computer operation.

5. Wind components are extracted from the profiles at

the height of the constant-pressure surface and a resultant wind is computed.

6. Thermal winds are determined for 6-km. layers surrounding each pressure surface.

It is interesting to note that rather large discrepancies appear to exist between rocketsonde and support rawinsonde temperatures observed at levels above 30 km. and within relatively short time intervals. According to figure 5 (after Finger and Woolf [8]), the difference between reported values at 5 mb. may average more than 5°C., with the rawinsonde temperature lower than the rocketsonde. Although an accurate determination of the average differences is difficult because of the extreme dispersion of values, it nevertheless suggests that the two temperature-measuring systems are not truly compatible above 30 km. This incompatibility presents the meteorologist with a serious analysis problem.

4. ANALYSIS PROCEDURE

Conventional techniques, including differential analysis methods, are being utilized to construct the 5-, 2-, and 0.4-mb. charts. The analysis system consists of the following steps.

1. The temperature field for a selected constant-pressure system is analyzed with the aid of processed information. At the 5-mb. level allowance is made for any discrepancies between rocketsonde and rawinsonde temperature measurements. Since data for an entire week are available at each station, reported "on-time" temperatures may be checked for temporal continuity. If the "on-time" temperature is missing, an estimate may be obtained by interpolation. In addition, computed thermal winds are utilized as a guide in making localized adjustments to the temperature pattern.

2. A mean temperature field within the layer between the previously analyzed lower surface and the selected surface is derived graphically. This mean field represents a geopotential thickness, which when added to the lower-level height field, yields a smooth, conservative first approximation to the contour pattern at the upper surface. (The standard [4] thickness between 10 and 5 mb. is approximately 4720 m.; between 5 and 2 mb., 6660 m.; and between 2 and 0.4 mb., 12605 m.)

3. Winds and heights for individual stations are used to adjust the first approximation of the contour field. Winds are accorded the highest priority for this adjustment.

4. The analysis is checked for vertical and temporal consistency. For example, centers of systems, as well as ridges and troughs, are examined with the aid of all available data to verify vertical slope and movement with time. Time-height sections and height-change charts are especially useful for these purposes. Additional data considered for the analysis include rocketsonde observations taken at Sardinia by the German Meteorological Service [2] and results of rocket-grenade and pitot-static tube experiments conducted at Wallops Island and Fort Churchill [17].

The above procedures appear to produce excellent results at 5 mb., and are successfully applied to obtain the 2- and 0.4-mb. charts. Generally, only slight adjustments of the first approximation height fields are necessary at the 5- and 2-mb. levels. However, rather formidable analysis problems are evident at the 0.4-mb. level. Foremost among these is the sparsity of observations. Another difficulty is the apparent occurrence of large day-to-day temperature changes, at times exceeding 10° C., as well as rapid oscillations within many wind profiles. It is not the intent of this paper to attribute these changes either to real variations or to error. Whatever the cause, the result is that the analyst must consider every sounding for its individual peculiarities. A further analysis problem arises from the apparent intersection of the stratopause with the 0.4-mb. level. Since the normal stratospheric temperature inversion ceases at the stratopause level, the graphical method for obtaining mean temperature, which depends on the existence of a linear profile, is no longer valid. This is especially true in lower latitudes, as will be shown later.

5. ANALYZED CHARTS

A substantial increase in number of observations during the autumn of 1964 afforded the analysts an opportunity to gain proficiency in high-level analysis techniques. Therefore the series was initiated with that period. Examples of completed charts for October and early November are shown in figures 6 through 11. The computer-analyzed 10-mb. chart [6] for October 28 (fig. 6) illustrates a typical early winter circulation pattern, dominated by a deepening cyclone centered over northern latitudes. This system first developed over the subarctic during the latter part of August, and gradually drifted poleward. The associated cold air center of approximately −65° C. is situated near the low center. Of interest is the zonal asymmetry, especially noticeable in the temperature field. For example, the cold air located near the coast of Greenland is at nearly the same latitude as the −45° C. warm center over eastern Siberia.

The 5-mb. pattern (fig. 7) is strikingly similar to that at 10 mb. throughout the analysis area. A temperature inversion between these two levels is indicated at all latitudes, and is most pronounced over the subtropics and in the ridge located over the Alaskan-Siberian region. The time-height section of smoothed winds for Fort Greely (fig. 12) was utilized as an aid in substantiating the existence and tracing the behavior of the Alaskan ridge at the 2- and 0.4-mb. levels (figs. 8 and 9). As can be seen from the section, winds immediately adjacent to October 28 increase in strength with height and veer slowly from westerly at 10 mb. (30 km.) to nearly northerly at 0.4 mb. (55 km.). Thus eastward slope and intensification of the ridge with height are indicated. Examina-

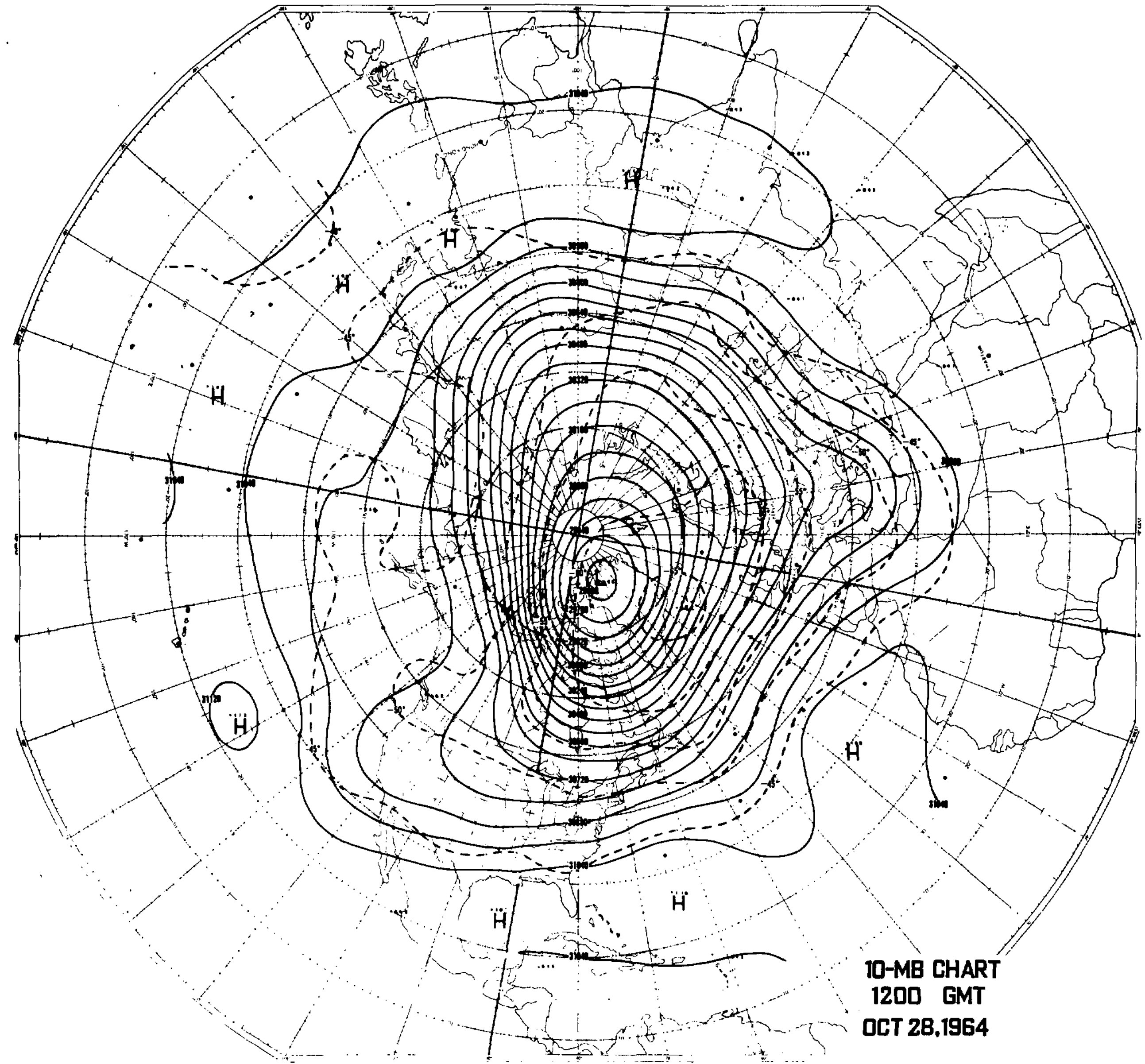

FIGURE 6.—Computer-analyzed 10-mb. chart for October 28, 1964 [6]. Contour (solid lines) interval is 80 m.; isotherm (dashed lines interval, 5° C.

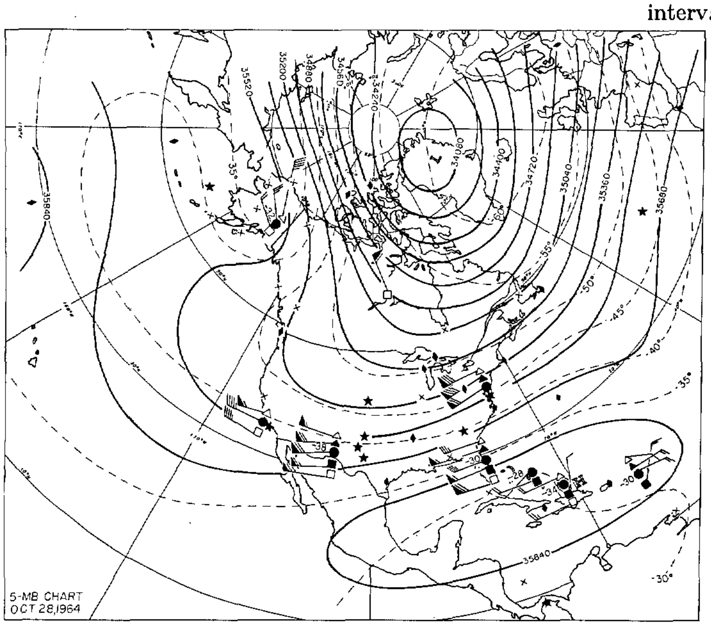

FIGURE 7.—5-mb. chart for October 28, 1964. Contour (solid lines) interval 160 m.; isotherm (dashed lines) interval 5° C. Plotted rocketsonde observations (winds in knots and temperatures in °C.) are shown for map day (●), one day previous (▲) and one day subsequent (■). Earlier and later data are denoted by (△) and (□), respectively. Locations and times of rawinsonde observations are identified as follows: (★), map-day; (×) one day before or after; (♦), two days before or after.

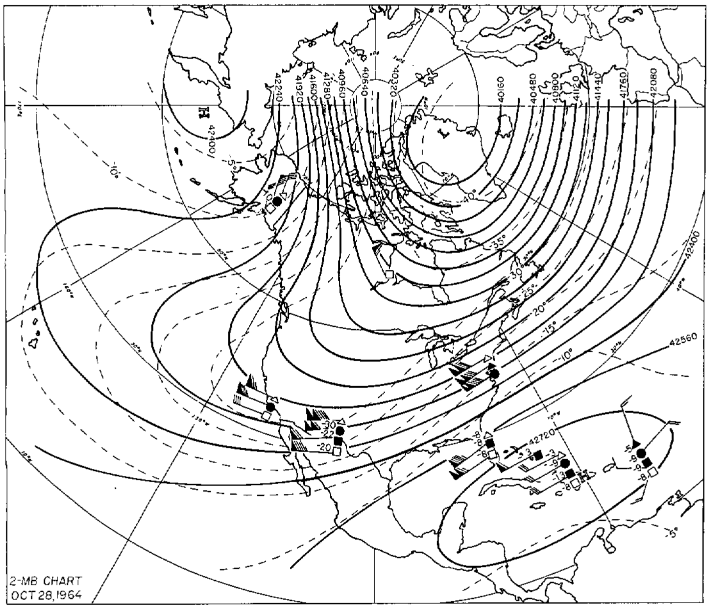

FIGURE 8.—2-mb. chart for October 28, 1964. Contours, isotherms, and plotted rocketsonde data as in figure 7.

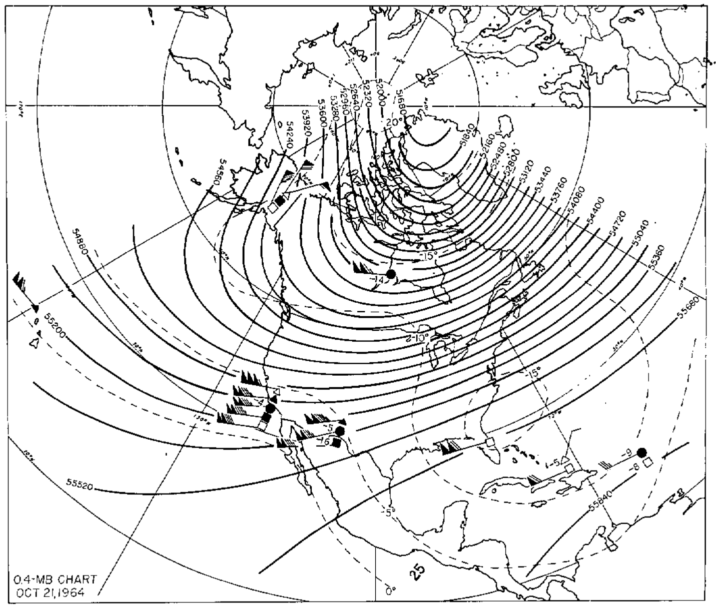

FIGURE 10.—0.4-mb. chart for October 21, 1964. Contours, isotherms, and plotted rocketsonde data as in figure 7.

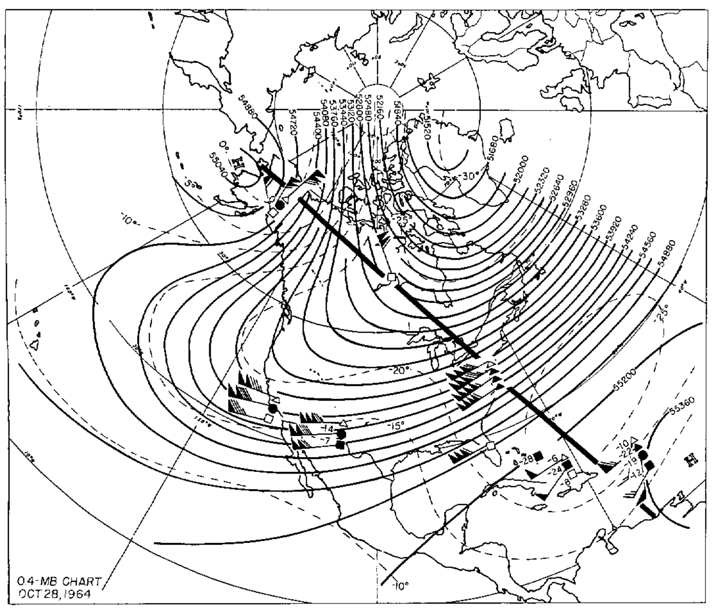

FIGURE 9.—0.4-mb. chart for October 28, 1964. Contours, isotherms, and plotted rocketsonde data as in figure 7. Heavy line denotes orientation of cross section shown in figure 13.

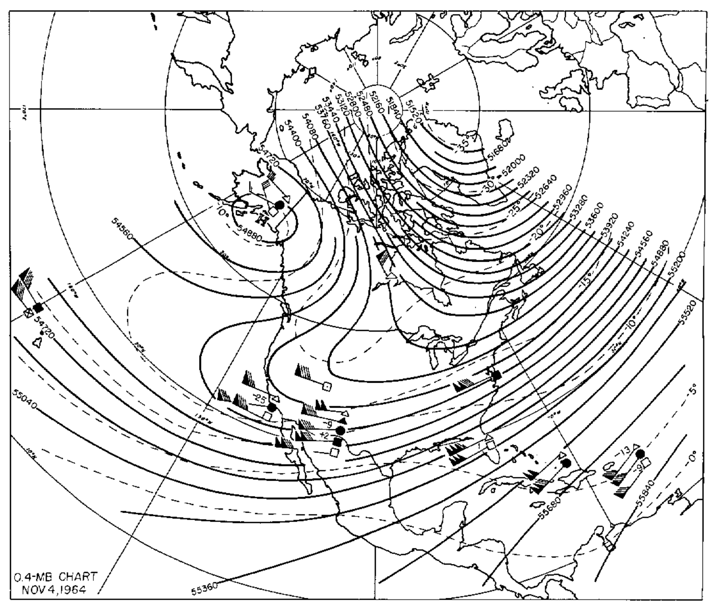

FIGURE 11.—0.4-mb. chart for November 4, 1964. Contours, isotherms, and plotted rocketsonde data as in figure 7.

tion of 10-mb. charts for early November reveals that this feature rapidly developed a closed circulation. The vertical extent of the center to the 0.4-mb. level on November 4, (fig. 11) is suggested by the light and variable winds shown on the time section.

The vertical cross section for October 28, shown in figure 13, is oriented southeastward from the Aleutian anticyclone through the polar trough to the area of the subtropical anticyclone (see fig. 9 for line of section). This section includes soundings from stations located near the line, as well an analyzed temperatures, heights, and geostrophic winds interpolated at the intersection of the cross-section plane with the 0.4-, 2-, 5- and 10-mb. surfaces. Isobars drawn through the interpolated height values illustrate the intensification of the polar trough with increasing height. In addition, the generally southward tilt of the subtropical ridge line is indicative of the polar cyclone's expansion at the higher levels.

As previously mentioned, the intersection of the stratopause with the 0.4-mb. surface is evident in many analyses.

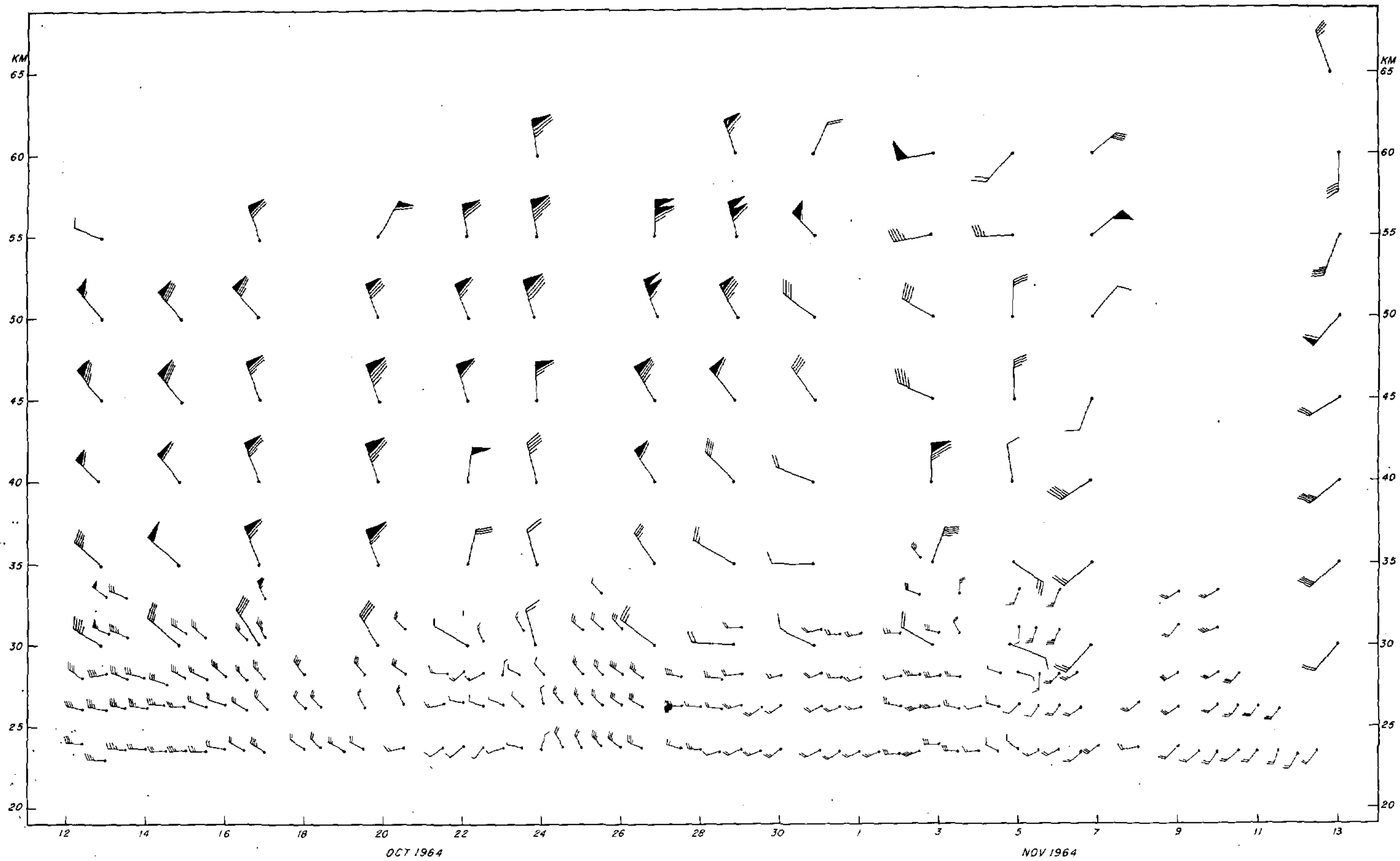

FIGURE 12.—Time-height section of winds (knots). Small symbols in lower part of diagram denote winds from rawinsonde observations at Fairbanks, Alaska; large symbols represent rocketsonde winds from Fort Greely.

From the observed temperatures (fig. 13), it can be seen that the stratopause is located well below the 0.4-mb. surface at lower latitudes. At Fort Greely it appears to be quite close to that surface. Unfortunately, temperatures at Churchill were available only during the previous week. However, these values were still increasing with height, suggesting that the stratopouse at that time was located well above the 0.4-mb. surface.

The high-level charts for autumn indicate rapid intensification of the polar cyclone with time. However, large-scale variations appear to be superimposed on this general trend. For example, height changes at the 0.4-mb. level associated with the rapid development of the Aleutian anticyclone during the period from October 21 to November 4 exceeded 1000 m. (see figs. 9, 10, and 11). Increases of this magnitude were centered over northwestern North America, while equally large decreases occurred during the beginning of the period over more southern latitudes. These latter changes were undoubtedly associated with a southward displacement of the polar trough. Rocketsonde temperatures observed during the two-week period, mainly at relatively low-latitude stations, substantiate a decrease in temperature followed by an increase over those areas. Unfortunately a similar series of temperatures at higher latitudes is not available.

The variations within the rapidly falling height field at 10 mb. can be seen on the graph (fig. 14) containing daily values of the polar cyclone central height during the 1964–65 stratospheric winter. The values were extracted from the series of computer-analyzed charts [6]. One of the large excursions in center height occurred during late October and early November. This evidence, combined with changes in lower latitudes at 5, 2 and 0.4 mb., suggests that the entire upper stratosphere over North America might have been affected. It is difficult to determine whether this phenomenon is cyclic in nature, although it may be argued that the portion of the 10-mb. graph for early winter contains several similar oscillations with a period between 10 and 15 days. The large-amplitude changes that occurred later in the season appear to mask the oscillation. Removal of a linear trend from the portion of the record up to December 5 results in the pattern shown in figure 14b. Warnecke [22], using rocket winds from Point Mugu during summer of 1960, found a perturbation with a period of approximately 13 days in both the speed and the direction of the prevailing easterly flow. If such a general oscillation exists, its cause and its phase structure with latitude and height remain to be determined.

In the course of analysis of charts for other seasons,

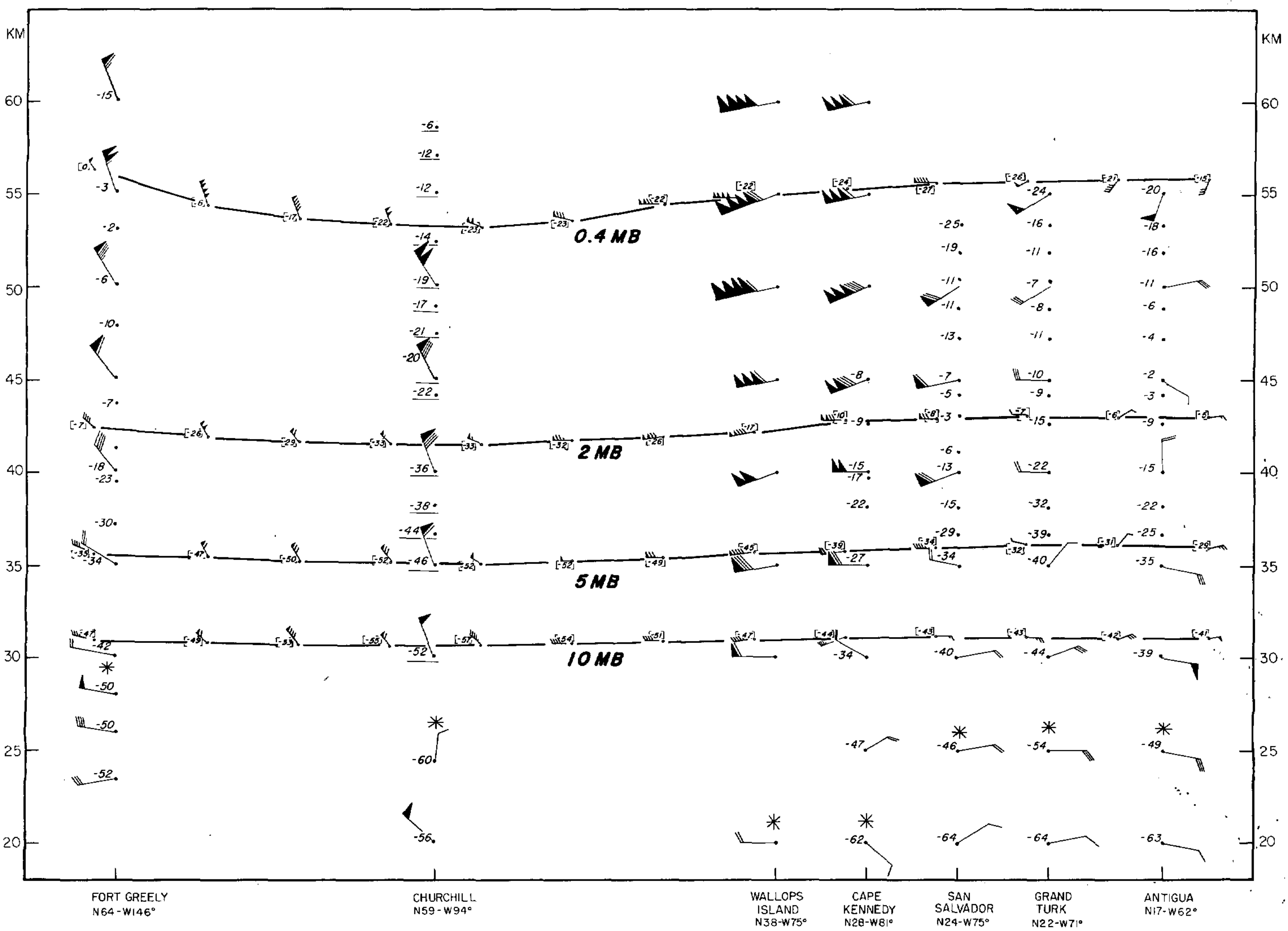

FIGURE 13.—Cross-section of winds (knots) and temperatures (°C.) from Fort Greely to Antigua for October 28, 1964, oriented as shown by heavy line in figure 9. Quasi-horizontal lines (isobars) represent intersections of the section with the various pressure surfaces. Bracketed temperatures and geostrophic winds (small symbols) plotted on these lines were extracted from the analysis. Rocketsonde data are shown at and above 30 km., with rawinsonde information below that level. Underlined temperatures at Fort Churchill are for October 21.

additional problems became apparent. During summer, for example, the circulation at the upper surfaces (2 and 0.4 mb.) would be expected to follow the pattern established for lower levels, i.e., rather uniform easterly flow about an anticyclone centered at or very near the pole. However, on a typical summertime 0.4-mb. chart (fig. 15), the majority of the reported rocketsonde winds exhibit significant southerly components. If these winds were to be given full weight in the analysis, the resulting pattern would consist of contours oriented from southeast to northwest, spiraling toward a high center located, apparently, over northern Europe. Such a pattern, it is felt, would be quite unrealistic.

The prevalence of positive meridional components in summertime rocketsonde winds has been noted previously [13]. In recent studies by Reed et al. [15, 16], utilizing MRN data for several summers, it was demonstrated that the meridional wind component due to the diurnal tide reaches maximum southerly strength about noon, local time. Since most MRN firings occur near noon, the measured winds naturally contain this component. In the same study, it was found that the daily mean meridional wind in summer is essentially zero.

On the basis of the findings described briefly above, it was decided to "correct" the observed winds for the tidal effect by considering only the zonal components in analysis, as is evident on the chart presented here (fig. 15). If the observations were taken on a truly synoptic basis, i.e., at the same Greenwich time rather than the same local time, it would of course be possible—and necessary—to portray the worldwide tidal oscillation in synoptic analyses.

During 1964, rawinsonde observations from a number of stations included several temperatures, but few winds, for the 2-mb. level. Nearly all of these soundings were made with the aid of hypsometer-equipped radiosondes. Comparison of the rawinsonde temperature reports with

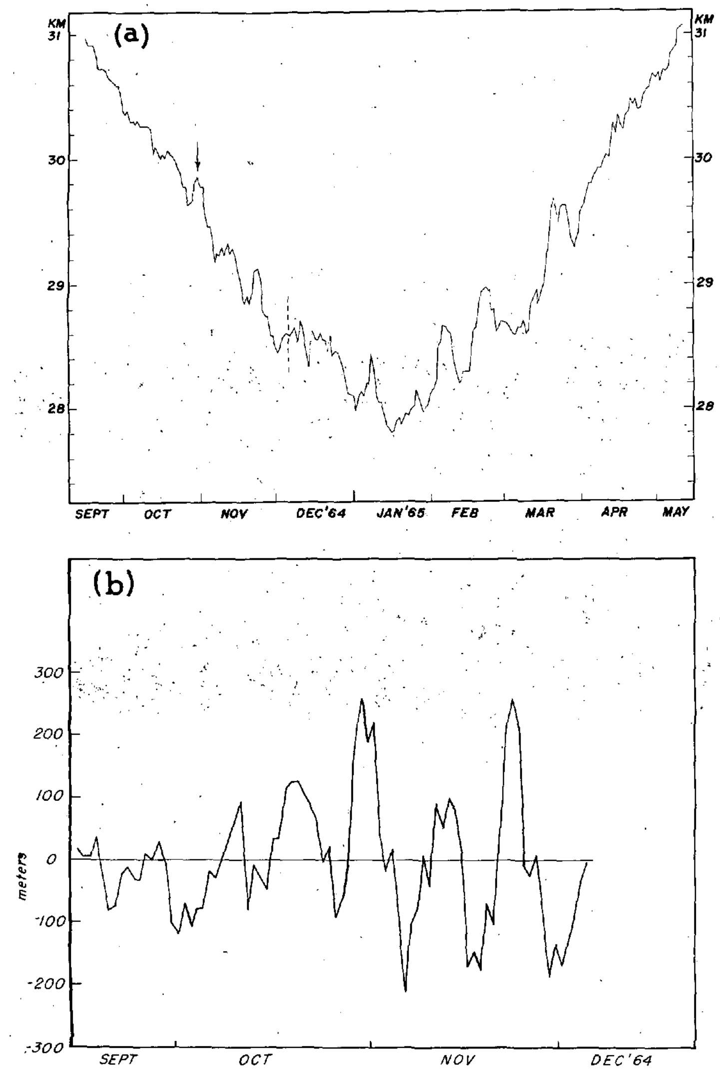

FIGURE 14.—(a) Central height of the 10-mb. polar cyclone, September 1964–May 1965. Arrow denotes peak in oscillation during period covered by high-level analyses (figs. 7–11). (b) Expanded view of portion of 10-mb. cyclone-center record up to December 5, 1964 (dashed line in (a)), after removal of linear trend.

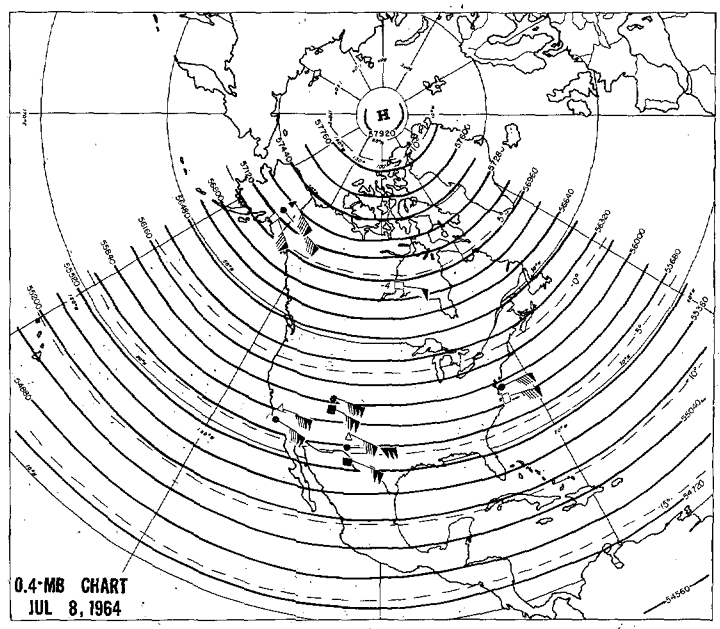

FIGURE 15.—0.4-mb. chart for July 8, 1964. Contours, isotherms, and plotted rocketsonde data as in figure 7.

the 2-mb. temperature fields analyzed from rocketsonde data yielded a mean difference of 19° C., with the former lower. Since the great majority of the very high rawinsonde ascents occurred in summer or at low latitudes, differences due to synoptic-scale variations should be small. Therefore, the mean difference of −19° C. should provide a reasonable measure of the discrepancy between rawinsonde and rocketsonde temperatures at 2 mb. It is interesting to note, in this regard, that the analyzed curve in figure 5, when extended to 2 mb., gives a rawinsonde-minus-rocketsonde difference of −16° C.

6. CONCLUSIONS

Although careful consideration of high-level data allows a broadscale depiction of circulation patterns up to 0.4 mb. (55 km.), the sparsity of reports requires an increasing amount of subjectivity as the analysis proceeds to higher levels. However, it is firmly believed that with the system employed, the final product is considerably more substantial and well-founded than the product of an "analyst's imagination." Unfortunately, at the present time the Meteorological Rocket Network stations are not distributed, nor are observations scheduled, in a manner conducive to synoptic analysis. With regard to the former problem, there is an acute need for several additional sites north of 35° N. For example, the wintertime circulation could be described more accurately with the aid of observations from a site near the western or central portion of the United States—Canadian border. An additional station situated in the extreme northeastern United States or Newfoundland would be of great value. Furthermore, it is hoped that the recently activated site at Thule, Greenland will soon become a regularly reporting MRN station. The non-synoptic timing of MRN firings leads to the presence of significant tidal components in observed winds, which render the construction of consistent synoptic patterns difficult. This problem is particularly serious during the spring and fall transition periods, when prevailing winds are relatively light and variable.

The IQSY analyses constructed to date tend to confirm previous indications that the wintertime polar cyclone gradually intensifies and expands with increasing height. In addition, the large-scale Aleutian anticyclone appears to extend upward through the entire 10- to 0.4-mb. layer, although the vertical structure of this system, including its slope within the layer, is difficult to define. Finally, several charts, coupled with information from a series of daily 10-mb. analyses, suggest the existence of large-scale pulsations of stratospheric pressure surfaces. Whether these pulsations are periodic in nature or are a random manifestation of changing circulation patterns remains to be investigated.

The definition of small-scale perturbations within the general circulation is not possible at this time. However, many time-height sections presented in the literature, in addition to those constructed during the initial analysis phase of the project, suggest complex variations within both reported temperatures and winds. A substantial increase in the station density of the Meteorological Rocket Network as well as a greater frequency of observations at individual stations may be necessary before the validity of these perturbations can be verified.

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Messrs. M. E. Gelman, L. J. Hortch, and H. M. Hess are the project analysts. Messrs. L. P. Mannello, J. A. Booth, and S. F. Wilkes are carrying out the involved data processing and plotting. Messrs. W. P. Townshend and J. H. Yeakel are responsible for the computer operations.

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REFERENCES

1. R. W. Armstrong, "Improvement in Accuracy of the ML-419 Radiosonde Temperature Element for Heights Above 50,000 Feet and Up to 150,000 Feet," *Technical Report* ECOM-2634, U.S. Army Electronics Command, Fort Monmouth, N.J., 1965, 55 pp.
2. W. Attmannspacher, "Report on the Participation of Two German Meteorological Service Specialists in the Launching and Measuring of Meteorological Research Rockets in Sardinia in Spring 1964," *Scientific Report* No. 2 (6th year), Project Cell Structure of the Atmosphere, U.S. Army Contract DA/91-591-EUC-3237, 1965.
3. W. Barr, "Corrections for Radiational Error of Radiosonde Temperature Measurements in the Stratosphere," U.S. Army Electronics Command, Fort Monmouth, N.J., 1966 (personal communication).
4. Committee on Extension to the Standard Atmosphere, *U.S. Standard Atmosphere, 1962*, Washington, D.C., 1962, 278 pp.
5. W. A. Drews, "Final Report on Research and Development to Improve Temperature Measurements at High Altitudes," TR-PL-8876, Atlantic Research Corporation, Alexandria, Va., 1966.
6. Environmental Science Services Administration, "Daily 100-, 50-, 30-, and 10-Millibar 1200 GMT Synoptic Weather Maps of the IQSY Period," National Weather Records Center, Asheville, N.C., 1966 (microfilm).
7. F. G. Finger, R. B. Mason, and S. Teweles, "Diurnal Variation in Stratospheric Temperatures and Heights Reported by the U.S. Weather Bureau Outrigger Radiosonde," *Monthly Weather Review*, vol. 92, No. 5, May 1964, pp. 243-250.
8. F. G. Finger and H. M. Woolf, "Diurnal Variation of Temperature in the Upper Stratosphere as Indicated by a Meteorological Rocket Experiment," *Journal of the Atmospheric Sciences* (in press).
9. F. G. Finger, H. M. Woolf, and C. E. Anderson, "A Method for Objective Analysis of Stratospheric Constant-Pressure Charts," *Monthly Weather Review*, vol. 93, No. 10, Oct. 1965, pp. 619-638.
10. T. J. Keegan, "Synoptic Patterns at 100,000 to 200,000 Feet," *Air Force Surveys in Geophysics* No. 140, Air Force Cambridge Research Laboratories, Bedford, Mass., 1962, pp. 195-210.
11. Meteorological Rocket Network Committee, *Data Report, Meteorological Rocket Network Firings* (IRIG Document 109-62), vols. 29-52, White Sands Missile Range, N. Mex., 1965—66.
12. Meteorological Rocket Network Committee, (ed.), "The Meteorological Rocket Network," IRIG Document 111-64, White Sands Missile Range, N. Mex., 1965.
13. B. T. Miers and N. J. Beyers, "Rocketsonde Wind and Temperature Measurements Between 30 and 70 km. for Selected Stations," *Journal of Applied Meteorology*, vol. 3, No. 1, Feb. 1964, pp. 16-26.
14. E. P. Ney, R. W. Maas, and W. F. Huch, "The Measurement of Atmospheric Temperature," *Journal of Meteorology*, vol. 18, No. 1, Feb. 1961, pp. 60-80.
15. R. J. Reed, D. J. McKenzie, and J. C. Vyverberg, "Further Evidence of Enhanced Diurnal Tidal Motions Near the Stratopause," *Journal of the Atmospheric Sciences*, vol. 23, No. 2, Mar. 1966, pp. 247-251.
16. R. J. Reed, D. J. McKenzie, and J. C. Vyverberg, "Diurnal Tidal Motions Between 30 and 60 km. in Summer," *Journal of the Atmospheric Sciences*, vol. 23, No. 4, July 1966, pp. 416-423.
17. W. Smith, J. Theon, L. Katchen, and P. Swartz, "Temperature, Pressure, Density, and Wind Measurements in the Upper Stratosphere and Mesosphere, 1964," NASA TR R-245, National Aeronautics and Space Administration, Greenbelt, Md., Aug. 1966.
18. S. Teweles, "Application of Meteorological Rocket Network Data," NASA SP-49, National Aeronautics and Space Administration, Washington, D.C., 1964, pp. 15-35.
19. O. W. Thiele, "Density and Pressure Profiles Derived from Meteorological Rocket Measurements," *Technical Report* 108, U.S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1961.
20. N. K. Wagner, "Theoretical Accuracy of a Meteorological Rocketsonde Thermistor," *Journal of Applied Meteorology*, vol. 3, No. 4, Aug. 1964, pp. 461-469.
21. G. Warnecke, "Eine synoptische Höhenwetterkarte für das 0.5 mbar.-Niveau vom Sommer 1960," *Berliner Wetterkarte*, Beil. 37, 1961.
22. G. Warnecke, "Über die Zustandsänderungen der nordhemisphärischen Stratosphäre," *Meteorologische Abhandlungen*, vol. 28, No. 3, 1962, pp. 26-28.
23. W. L. Webb, W. I. Christensen, E. P. Varner, and J. F. Spurling, "Inter-Range Instrumentation Group Participation in the Meteorological Rocket Network," *Bulletin of the American Meteorological Society*, vol. 43, No. 12, Dec. 1962, pp. 640-649.

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